MODERN CONSTRUCTION PROJECT MANAGEMENT TECHNIQUES: CURRENT UTILIZATION BY NATIONAL CAPITAL AREA CONSTRUCTION FIRMS

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CONSTRUCTION FIRMS

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CHAPTER I

INTRODUCTION

Subject

Of all the management endeavors of man, the field of Construction Management can claim to be second in age only to Agricultural Management, which it was originally developed to support.[1] The construction industry is one of the basic underpinnings of any modern industrial society. In 1971 new construction amounted to over ten percent of the overall Gross National Product (GNP) of the United States, exceeding $108 billion in value.[2]

In a highly competitive industry such as construction, an early adoption of new innovations, such as new, superior project management techniques, which might give one an edge over his competitors might be expected. A number of new project management techniques have been developed within the past thirty years which fall within this category.

Until the Second World War, the American construction industry utilized the Gantt Chart almost exclusively in the

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[1] R. S. Kirk, S. Whithington, A. B. Darling, F. G. Kilgore, Engineering in History (New York: McGraw-Hill Book Company, Inc., 1956), p. 9.

[2] Economic Report of the President, Transmitted to the Congress, January, 1972 (Washington, D. C.: U. S. Government Printing Office, 1972), p. 240.

management of its projects. This bar-chart schedule gave managers at least a rough composite, or systems, view of the management of the overall project, which was itself basically a suboptimization process.[1] Under the stresses of war, the need for a thorough, systematized approach to project management of production contracts led the Navy Department to develop the Line of Balance technique, which it applied also to highly repetitive forms of construction such as housing tracts and high rise buildings.[2] During the late 1950's, the Program Evaluation and Review Technique (PERT) and the Critical Path Method (CPM) for project management were developed almost simultaneously for use by the Navy Special Projects Office and the DuPont Company, respectively.[3] Adaptation of these techniques for use in construction was undertaken very quickly by both the Navy and the Associated General Contractors of America (AGC).[4] These techniques bring into clear visibility the interrelationships of the various elements of the project and, if a time estimate is assigned to each element, allow the identification of the most critical elements upon which the earliest completion of the job depends. They can be constructed either manually, or for more

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[1]A. J. Ackerman, C. H. Locher, Construction Planning and Plant (New York: McGraw-Hill Book Company, Inc., 1940) pp. 46-51.

[2]Network Analysis for Construction Project Planning (Port Hueneme, Calif.: Naval Achool, Civil Engineer Corps Officers, 1972), p. 85.

[3]Harold Koontz and Cyril O'Donnell, Principles of Management: An Analysis of Management Functions (New York: McGraw-Hill Book Company, Inc., 1972), p. 625.

[4]The Associated General Contractors of America, CPM in Construction: A Manual for General Construction Contractors (Washington, D. C.: Associated General Contractors of America, 1965), p. 10.

complex projects, with the use of an electronic computer. If properly updated, they give the contractor a complete picture at any given moment of project status. With cost information introduced into the network, they may be used to predict cash flow with a high degree of accuracy, a distinct advantage when planning for financing of labor and materials.[1]

The Operations Research disciplines have also contributed to the project management methods that are available to the construction manager. Especially applicable are techniques for assignment of limited resources to numerous simultaneous tasks, inventory management and operations involving waiting time for service.[2]

In the early 1960's it appeared that almost universal adoption of CPM might lead the way to a rapid transition to modern project management. The prestigeous weekly construction industry magazine Engineering News Record predicted an abandonment of the traditional bar (Gantt) chart in 1963.[3] It also raised the question of whether application of modern methods for project management would not become a requisite condition for remaining in the construction business.

> For the crude bar charts traditionally used in construction scheduling CPM substitutes a network diagram that enables the contractor to identify critical tasks and shows him how to best allocate his resources. . . through linear programming the contractor would be able to calculate

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[1] Ibid., p. 57.

[2] James M. Antill, Civil Engineering Management (New York: American Elsevier Publishing Company, Inc., 1970), p. 14.

[3] "Bye-Bye Bar Chart," The Story of the Critical Path Method: Reprinted from Engineering News Record, (New York: McGraw-Hill Publishing Company, Inc., 1963), p. 23.

> the best way to allocate his available men, equipment, and materials among concurrent projects . . . . CPM, however, marks a major breakthrough for scientific management in construction, comparable to a major advance in technology . . . . in the intensively competitive field of construction, progress in management techniques as well as technology may well be a condition to survival.[1]

The Navy's Bureau of Yards and Docks became a pioneer in the utilization of CPM and other network techniques to government construction contracts with the issuance of its BuDocks Instruction 5200.10, Subject: Application of Network Analysis Systems to Construction Projects; Policy Concerning in August of 1962. Training in Network Analysis for Construction Projects was begun for newly commissioned Civil Engineer Corps Officers and BuDocks civilian employees at the Naval School, CEC Officers in 1961. Seabee Battalions of the Naval Construction Force also adopted CPM on a widespread basis.[2] A continual growth in the use of network analysis systems throughout Department of Defense construction agencies led to the issuance of a uniform regulation to govern its use and set forth mandatory requirements in Armed Forces Procurement Regulation 7-604.5 which was issued in 1968.[3]

The construction industry's primary national organization, the Associated General Contractors of America, contributed to standardizing network analysis techniques within the industry,

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[1] "CPM and Survival," The Story of the Critical Path Method: Reprinted from Engineering News Record, (New York: McGraw-Hill Publishing Company, Inc., 1963), p. 23.

[2] Network Analysis for Construction Project Planning (Port Hueneme, Calif.: Naval School, CEC Officers, 1972), p. 2.

[3] Armed Services Procurement Regulation 7-604.5, Contractor Prepared Network Analysis Systems (Washington, D. C.: Government Printing Office, April, 1968).

publishing a CPM manual in 1965,[1] and expanding this treatment with an additional book on cost control applications of CPM in 1968.[2]

As a member of the Navy Civil Engineer Corps, the writer was either involved with Navy construction contracting or closely associated with contract administrators throughout the decade of the 1960's. Through these contacts, he became aware that there existed among them a general opinion that CPM and associated operations research techniques were not living up to the high expectations expressed above. A general feeling existed that contractors were treating Navy-required network analysis as a bother that had to be lived with rather than as a valuable tool for project management. This perception by the writer was reinforced during a tour as Academic Director of the Naval School, Civil Engineer Corps Officers, where he had the opportunity to discuss the subject with students in the Network Analysis Course over a period exceeding two years. Recent interviews with Navy construction contract administration officials at varying levels in the Washington, D. C., hierarchy established that they also hold this view.

Perhaps construction industry and government agency officials were naive in expecting a rapid, universal acceptance of these new project management techniques. Social psychologists

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[1]The Associated General Contractors of America. CPM in Construction: A Manual for General Construction Contractors (Washington, D. C.: The Associated General Contractors of America, 1965).

[2]The Associated General Contractors of America. Cost Control and CPM: A Manual for General Construction Contractors (Washington, D. C.: The Associated General Contractors of America, 1968).

have long been aware that people have an inherent aversion to change.[1] Installing new management systems takes especially careful planning.[2]

Writers who have examined the rate of diffusion of innovations have found consistent, substantial time lag between the introduction of innovations and their general adoption. Edwin Mansfield found that the mean adoption period for various industrial innovations was fourteen years, with a deviation of sixteen years. He concluded that the diffusion process is basically a learning process, and that there seem to be four principal factors which govern how rapidly the utilization of an innovation approaches its ultimate level. These are (1) the extent of the economic advantage over older methods or products, (2) the extent of uncertainty associated with the use of the innovation when it first appears, (3) the extent of commitment required to try out the innovation and (4) the rate of reduction of the initial uncertainty regarding the innovation's performance.[3] Everett M. Rogers undertook the synthesis of all the literature dealing with the diffusion of innovations and the development of a general theory of this diffusion. He concluded that there are five characteristics of innovations which determine how rapidly they are adopted: (1) relative advantage, or the degree to which

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[1]Lester Coch and John R. P. French, Jr., "Overcoming Resistance to Change," in People and Productivity, ed. by Robert A. Sutermeister (2nd ed.; New York: McGraw-Hill Book Company, 1969), p. 406.

[2]Lawrence K. Williams, "The Human Side of Systems Change," in Management Systems, ed. by Peter P. Schoderbeck (2nd ed.; New York: John Wiley and Sons, Inc., 1971), pp. 388-392.

[3]Edwin Mansfield, The Economics of Technological Change (New York: W. W. Norton and Company, Inc., 1968), pp. 99-134.

the innovation is superior to the ideas it supercedes, (2) compatibility, the degree to which the innovation is consistent with the existing values and experiences of the adopters, (3) complexity, or the degree to which an innovation is relatively difficult to understand and use, (4) divisibility, or the degree to which the innovation may be tried on a limited basis and (5) communicability, the degree to which the results of an innovation may be diffused to others. Defining the "rate of adoption" as the relative speed with which an innovation is adopted by members of a social system, he concludes that:

> The rate of adoption of new ideas is affected by the interaction effect, the process through which individuals in a social system who have adopted an innovation influence those who have not yet adopted. It is through interaction that individuals in a system internalize the relative advantage of an idea, as well as its other characteristics.[1]

Following the lead of agricultural sociologists, Rogers, accepting the general findings that the diffusion of innovations over time assume a normal distribution, segregated those who have accepted an innovation into "adopter categories," delineated by relative time required to adopt the innovation.[2] In postulating his suggested general theory of innovation diffusion, Rogers sets forth over fifty generalizations to provide a skeleton summary of the major conclusions of what was known about innovation diffusion at the time.[3] The majority of these deal

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[1]Everett M. Rogers, Diffusion of Innovations (New York: The Free Press, 1962), p. 146.

[2]Ibid, p. 162.

[3]Ibid, pp. 311-314.

with the characteristics of the innovator himself. Mansfield listed the characteristics of business enterprises which he felt affected their response to new innovations.[1]

In a pilot project currently being conducted by the Naval Facilities Engineering Command in Charleston, South Carolina, there has been observed a high degree of contractor acceptance and enthusiasm for a government required computer managed CPM scheduling and contractor payment system, suggesting that in that area, the construction industry is well along towards adoption of modern project management techniques. The present study attempted to examine the degree of acceptance of specific modern project management techniques by construction contractors in the National Capital area, concurrently attempting to compare the findings with selected generalizations from Rogers' innovation diffusion theory.

The Research Question

The principal question of this paper is: Is significant use being made of modern project management techniques by National Capital area construction contractors? Subsidiary to the basic question are:

A. What are modern construction project management techniques as delineated in the literature of construction management?

B. To what extent are the above techniques in use, and what are the distributions of their adoption over time?

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[1]Edwin Mansfield, op. cit., p. 123.

C. Have a significant number of contractors accepted modern project management techniques because of their expected or proven effectiveness as opposed to being coerced to their use by their customers?

D. What factors, if any, have given impetus to the use of modern project management techniques in the recent past?

E. What were selected characteristics of contractors in the various "adopter categories" as compared with those predicted by Rogers?[1]

Scope and Organization of the Study

This study is primarily investigative in nature. Its concern is with respect to the current behavior of construction contractors in the management of their projects rather than a hypothesis on what their practices should be.

In conducting a study of this type, the population to be considered and the methodology to be utilized must be held within manageable limits. The building industry in the United States is generally divided into two segments. One segment deals in the construction of family residences and has organized the National Association of Homebuilders as its spokesman and lobbying organization. The remainder of the industry, dealing with all other facets of construction is structured around the Associated General Contractors of America. This study deals with the latter group. The project management practices of homebuilders is beyond the scope of the study. The population selected for the study

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[1]Everett M. Rogers, op. cit., p. 185 and pp. 311-314.

was the membership of the AGC in the vicinity of the National Capital. This included both the entire membership of the District of Columbia chapter and those members of the Maryland and Virginia chapters who are headquartered in the environs of the Capital, fifty-one general construction contractors in all.

Dealing with a population of fifty-one members, it became possible to survey the entire population rather than just a sample. However, in dealing with this many firms, the writer concluded that the use of a printed questionnaire delivered and returned by the mails was the only practical medium for collection of the information desired. Despite the limitations inherent in this method, the writer's years of dealing with the construction industry convinced him of one distinct advantage from the method in a study of this type. Complete anonymity could be guaranteed concerning the data from each firm, assuring the respondents that their information could not possibly be used against them by competitors.

Of the fifty-two generalizations postulated by Rogers concerning the diffusion of innovations,[1] the number which can be practically treated in a questionnaire study is limited. On the one hand, the length of the questionnaire must be fairly short if one is to expect a busy businessman to take time away from his work to complete and mail back the form. There is also the problem of what information the respondents are likely to accept as valid study data, and what they might consider undue prying into their business operations or personal lives. Measurement

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[1] Ibid., pp. 311-314.

of the relative social status of contractors through the questionnaire, for instance, is extremely difficult, except, perhaps, through indirect indicators such as size of the firm or educational background. The specific generalizations which this study undertook to examine with respect to the target population were as follows:

A. Adopter distributions follow a bell-shaped curve over time and approach normality.

B. Awareness occurs at a more rapid rate than does adoption.

C. Cosmopolite information sources are most important at the awareness stage and localite information sources are more important at the evaluation stage.

D. Earlier adopters are younger in age than later adopters.

E. Earlier adopters have more specialized operations than later adopters.

F. Impersonal sources of information are more important than personal sources for relatively earlier adopters of innovations than for later adopters.

G. Cosmopolite sources of information are more important than localite sources of information for relatively early adopters of innovations than for later adopters.

H. Earlier adopters utilize information sources that are in closer contact with the origin of new ideas than later adopters.

I. Personal influence from peers is more important for relatively late adopters than for early adopters.

In as much as the study dealt with events which occurred as much as ten or twelve years prior to the study, the writer did not attempt to break questions concerning adoption into sequential phases of adoption, other than to differentiate between initial awareness and adoption.

Two questions were specifically added to the scope of the study at the request of the Naval Facilities Engineering Command contact points for this effort. These questions were first, what elements of the firm contribute to the use of a given technique within the firm and, second, in what phases of project management are the technique utilized.

The organization of this study generally follows the sequence of operations that were followed in its conduct.

Chapter II is a survey of modern construction project management techniques, aimed primarily at answering the first subsidiary research question.

Chapter III describes in detail how the study was conducted.

Chapter IV presents an analysis of the results of the questionnaire study.

Chapter V contains the writer's conclusions drawn from the study.

CHAPTER II

A BRIEF SURVEY OF MODERN CONSTRUCTION PROJECT MANAGEMENT TECHNIQUES

Antecedents

There is little evidence to ascertain the methods by which the construction specialist of the pre-modern era marshalled and applied the resources required to accomplish his projects. This is unfortunate, for construction was an important element of the many civilizations of pre-modern times. Reclamation projects with dams, irrigation and drainage made large scale societies possible; graded, crowned and bridged military roads combined with fortifications with walls, towers gateways and moats insured security; harbors constructed with care to include dredged channels, breakwaters, wharfs and support facilities evidence a blossoming of trade; massive religious edifices such as temples and pyramid tombs were undertaken.[1]

The technology upon which pre-modern construction was based was an accumulation of trial and error, intuition, artistry and the gross synthesis of experience, unsupported by science.[2]

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[1]"Engineering," Encyclopedia of the Social Sciences, Vol. 5 (New York: The Macmillan Company, 1931), p. 541.

[2]"Engineering," International Encyclopaedia of the Social Sciences, Vol, 5 (New York: The Macmillan Company, 1962), p. 70.

It was a matter of "craft mastery," and the economic benefits derived by the possession of such knowledge by an exclusive group of craftsmen interfered with the codification and transmission of all technological knowledge to society.[1]

There was also a pronounced contempt for technology amongst the intellectual communities of ancient times, and this factor, coupled with "craft mastery" delayed the transition to science as the basis of technology until the Sixteenth and Seventeenth Centuries. Engineering as a profession based upon the practical application of science dates from this period.[2] However, the application of scientific principles to the actual performance of work, as opposed to the design of the physical end product, did not occur until the latter years of the Nineteenth Century, an effort principally led by Frederick W. Taylor.[3] Prior to this time, job planning and supervision in the construction industry was mainly a process of suboptimization. Specialized supervision of each phase of the work by functional foremen, such as carpentry foremen, steelworker foremen, etc., was counted on to produce the most effective accomplishment of each phase and, hopefully, the most effective accomplishment of the job as a whole.[4]

In 1897 Henry Lawrence Gantt, an associate of Taylor, introduced a management took, called the "Graphical Daily Balance in Manufacture," which was to become the first overall project

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[1]Ibid., p. 70.

[2]Ibid., p. 70.

[3]Encyclopedia of the Social Sciences, op. cit., p. 544.

[4]Robert L. Puerifoy, Construction Planning, Equipment and Methods (New York: McGraw-Hill Book Company, 1970), p. 53.

management tool of the construction manager. The elements of a job, the plan of management for their accomplishment and progress at a particular time could be simply portrayed by this medium. Its format could be easily understood by supervision and tradesmen alike. It was not, however, until the strains of the First World War severely taxed the capabilities of American industry, including those of construction, that this simple but effective device was widely adopted, taking the name of its developer as the "Gantt Chart."[1] By the beginning of World War II, it had become the mainstay of the construction industry as a project management tool. Construction management texts of the day made it the centerpiece of their discussions of project planning, scheduling and progress monitoring.[2] Both of itself and as an adjunct to more comprehensive techniques, it has retained its importance to the present day.[3]

The Gantt Chart is of great enough importance to warrant an illustration. In utilizing this device, planning, that is breaking down the project into work elements, and scheduling, determining the scope of each element and assigning a specific time to it, are usually performed simultaneously.[4] To aid in construction of the chart, a simple tabular schedule similar to

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[1]Henry Lawrence Gantt, Gantt on Management (New York: American Management Association and the American Society of Mechanical Engineers, 1961), p. 255.

[2]Frank Whitworth Stubbs, Jr., Estimates and Costs of Construction (New York: John Wiley and Sons, Inc., 1938), pp. 165-167.

[3]George E. Deatherage, Construction Scheduling and Control (New York: McGraw-Hill Book Company, 1965), p. 2.

[4]U. S., Department of the Navy, Bureau of Yards and Docks, Seabee Planners and Estimators Handbook, NAVDOCKS P-405 (Washington, D. C.: Government Printing Office, 1965), p. 241.

Table 1 is usually prepared. This may precede the construction of the chart or, more likely, proceed simultaneously with it. Figure 1 is the Gantt Chart corresponding to Table 1.

TABLE 1

TABULAR WORK SCHEDULE

Work Element	Unit	Quantity	Estimated Start	Estimated Finish
Ditching and Backfilling	CY	2,200	4-16	10-18
Install Valves	Each	25	7-16	10-16
Construct Valve Pits	Each	10	5-14	9-20
Install 12" Pipe	LF	12,600	4-30	10-16

CY = Cubic Yard LF = Lineal Feet

A large amount of calculations not directly represented on the charts and graphs are necessary to construct a schedule such as that shown. Man-hour and crew size estimates are required for each element. Some notion of the interrelation of the elements must be derived, many times primarily from the superintendents' experience base rather than from any systematic analysis. Care must be exercised to assure that the basis of these estimates is not lost. The type of chart shown is not a "total systems" management tool. Ackerman and Locher recommend backing up the Gantt Chart with separate equipment, personnel employment, materials and financial schedules, and with cumulative percentage schedules on critical elements.[1] Note, however, that the latter requirement may be met either by plotting completion percentage

[1]Adolph J. Ackerman and Charles H. Locher, Op. Cit., pp. 64-51.

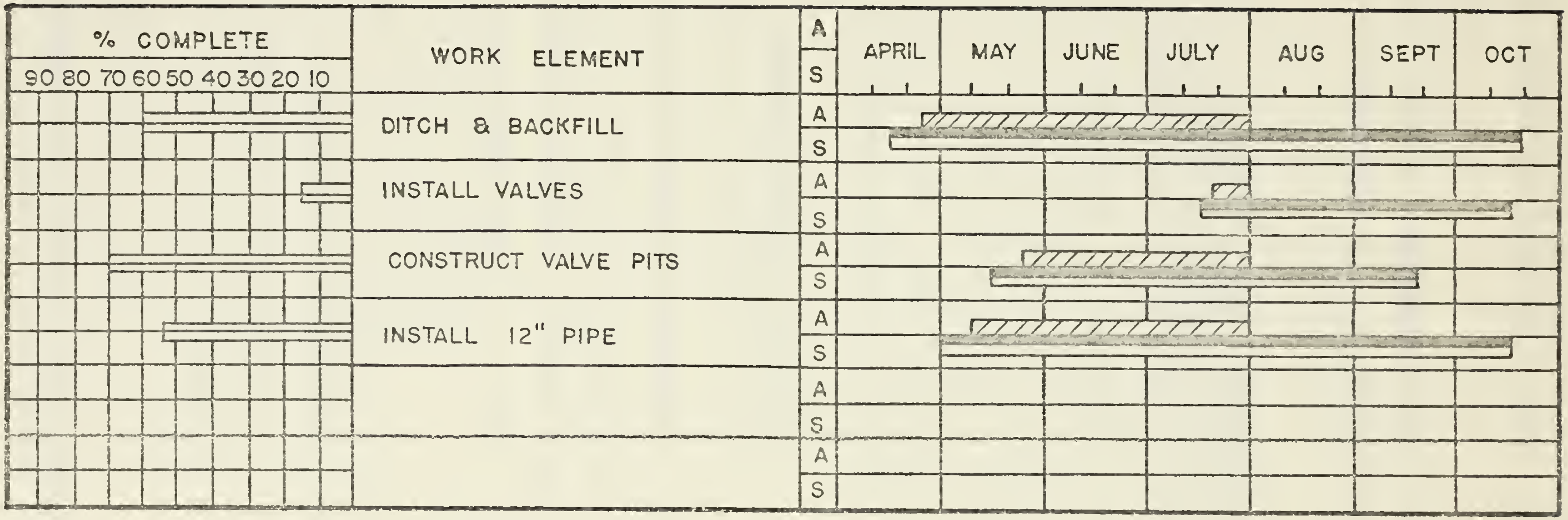

FIG. I --- GANTT CHART FOR PIPELINE JOB

in a separate section of the Gantt Chart or by plotting bars for progress to date above the schedule lines, both of which have been done on Figure 1.

As an overall project management tool, the Gantt Chart has its weaknesses. Deatherage has identified its most serious flaw as follows:

> The Gantt Chart . . . cannot show interrelated dependencies among activities (elements) connected with the various work classifications, nor will it point to those activities which are critical to completion of the work on schedule.[1]

Despite these weaknesses, it remained universally popular in the construction industry because of its basic simplicity and the ease with which it could be understood. Development of more sophisticated techniques did not occur until again the stresses of hot or cold war on American industry made them essential.

Line of Balance Technique

Line of Balance is a production control technique developed to monitor manufacturing processes. Like the Gantt Chart, it was originally conceived to eliminate bottlenecks in the production of ordnance equipment during wartime, but whereas Gantt was working for the Army, the U. S. Navy claims credit for the development of the Line of Balance.[2]

Line of Balance has been adapted for use in construction where a large number of identical end products are called for, and, therefore, the individual work elements for each product must be repeated many times in the accomplishment of the overall

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[1]George E. Deatherage, Op. Cit., p. 30.

[2]Network Analysis for Construction Project Planning, Op. Cit., p. 87.

project. Examples of this type of project are, in the private sector, high rise building construction (floors being the repeated product), townhouses and single family dwellings. In the military sector, construction of supply depots, ammunition storage points, fuel farms, pipeline construction and airfields with multiple hangars or revetments all fit this category. The technique is unfortunately inapplicable to the large percentage of construction projects which are special built to a unique design with substantial task repetition.

One of the principal advances associated with Line of Balance was the utilization of a graphical presentation on which the interdependencies of the various work elements in the construction of a single end product were portrayed along with the time required for each element. The device utilized to portray these relationships was a "lead-time chart," or as simply "the program."[1] Figure 2 is an example of such a "lead-time chart." Six work elements (A through F) are shown. The lead-time for each element (the latest start time) is indicated by the position of the

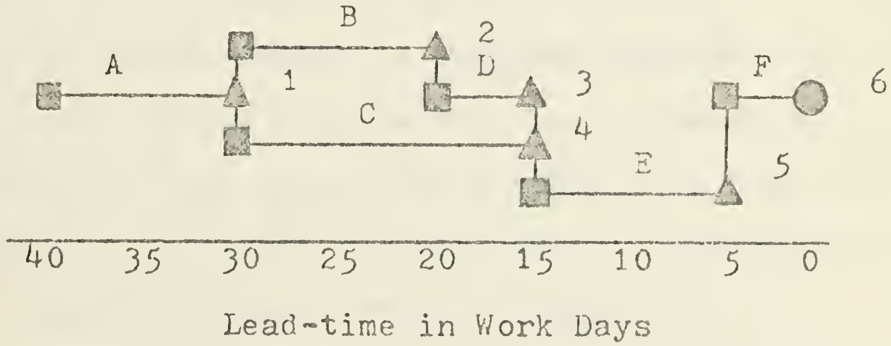

Figure 2 --- Lead-time Chart

[1]Peter P. Schoderbeck and Lester Digman, "Third Generation, PERT/LOB," Harvard Business Review, September-October, 1967, pp. 100-110.

starting event symbol (■). Dependency relationships are indicated by the numbered ending event coordination symbols (▲) and the connecting lines between work elements. Two additional graphical presentations are necessary to develop the Line of Balance as a working tool. The first of these, the "objective curve," is a simple plot of the end products on an axis against time on the other. Figure 3 illustrates an "objective curve." The "Program Progress Chart," a vertical bar chart showing the cumulative quantity produced of each work element at a given point in time, is illustrated in Figure 4. The numbers beneath the bars correspond to the ending event coordination symbols for the work elements from the "Lead-time Chart."

The Line of Balance is a stepped-down line graph overlaid across the "Program Progress Chart," which shows for each work element the number of elements which must have been completed by the date of the measurement (in this case, August 1) for the project to be on schedule as shown on the "Object Curve." The Line of Balance is projected from the "Objective Curve" to the "Program Progress Chart" utilizing data from the "Lead-time Chart."

Line of Balance can be a powerful tool in the project manager's hands, showing him exactly how he stands against his project schedule as far as each work element is concerned. He may thus use it to allocate his resources to maintain the project on schedule before problems get out of hand.[1]

Determining how widely the Line of Balance Technique is known and used among the contractors in the National Capital Area is one of the objectives of this paper.

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[1] Network Analysis for Construction Progress Planning, op. cit., p. 87.

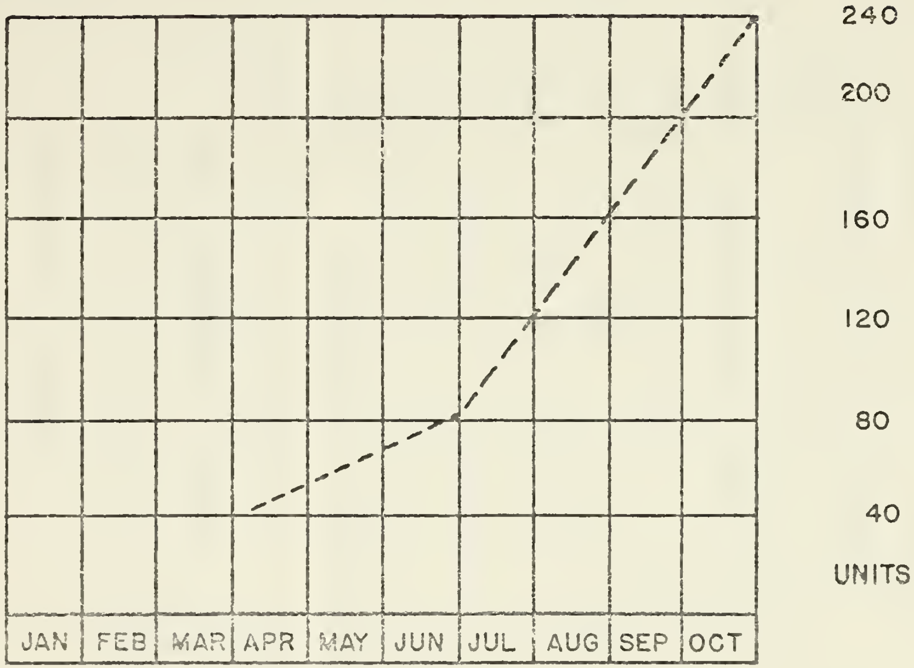

FIG. 3---OBJECTIVE CURVE

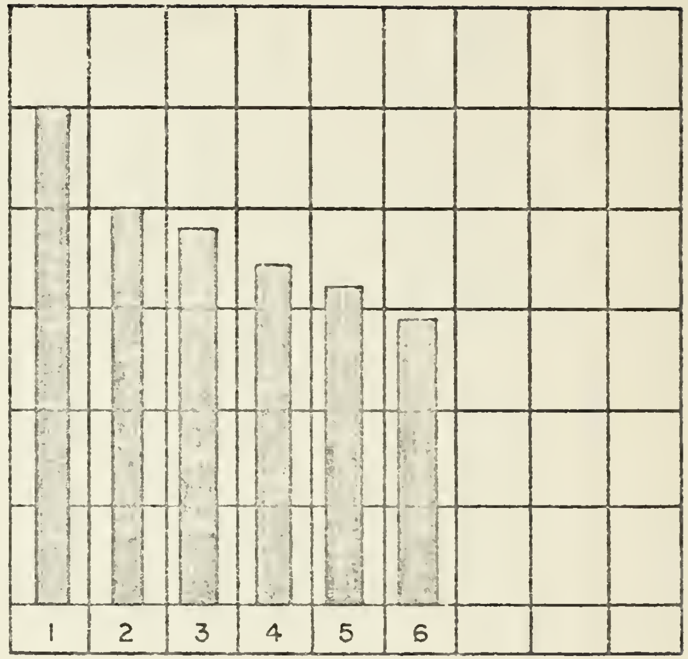

FIG. 4---PROGRAM PROGRESS CHART

Critical Path Method Technique

As previously noted (page 2), the Critical Path Method (CPM) and its near twin, the Program Evaluation and Review Technique (PERT) were developed almost simultaneously during the mid-1950's. PERT was developed for the Navy and CPM was developed by the Remington Rand Division of the Sperry Rand Corporation for DuPont.[1] At the heart of both techniques is the construction, either graphically, within a computer, or both, of a network of the interrelated dependencies of the work elements of the project. The concept of the network construction is very similar to that of the "Lead-time Chart" for the LOB, which was probably its direct ancestor. As with the techniques previously discussed, the first step in planning a job with either CPM or PERT is to break the job into manageable work elements. The next is to estimate the duration of each element. This requires the best analysis of the work elements that can be made, the determination of crew sizes and the number of hours or days that the crew is expected to take to do the work. It is in this step that CPM and PERT part company. PERT is primarily used on research efforts where little experience is available upon which to base estimates. Duration estimates in PERT are therefore developed on a probabilistic basis. A probability distribution is developed for each work element with an estimate for "optimistic time," "most likely time" and "pessimistic time." The "expected time" is then derived by developing a weighted average of the three.[2]

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[1] George E. Deatherage, op.cit., p. 29.

[2] Ibid., p. 30.

When dealing with construction projects, however, the great amount of uncertainty inherent in research projects is usually not present. Deatherage points out that,

> The average construction project does not contain so many variables, for, over the years, a tremendous amount of knowledge has been accumulated as to design, manufacturing, assembly and cost.[1]

The estimates used in CPM are deterministic, that is, the "expected value" is estimated directly from past experience. CPM is, therefore, almost exclusively the network technique utilized on construction projects. PERT is of very little importance in construction.[2] It will therefore not be discussed further, except to note that its use is similar to what will be described for CPM, with the added complexity engendered by the aspect of uncertainty.

Once estimates have been assigned to each work element, the longest path through the interdependency network can be found by adding the estimates for each element in each parallel tract from the beginning of the job to the end. The elements in this longest path are termed the "critical path," because their aggregate fixes the overall completion date of the project. A change in the amount of time required for one of these "critical work elements" engenders an identical change in the overall project completion time.

There will be some leeway as to when work elements not in the "critical path" are performed. The "earliest start time" for these elements will be set by completion of preceeding tasks,

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[1]Ibid., p. 30.

[2]Ibid., p. 30.

while their "latest start time" will be set by counting back from the project completion date established by the "critical path." The leeway between the earliest and latest times is known as "float."

The interdependency diagram typically used with CPM utilizes an arrow to depict each work element, with the critical path marked with a double slash (//). The earliest date at each point is typically shown on the diagram in a circle and the latest in a square. The duration of each work element (arrow) is usually shown, sometimes written below the arrow. Figure 5 illustrates this arrangement.

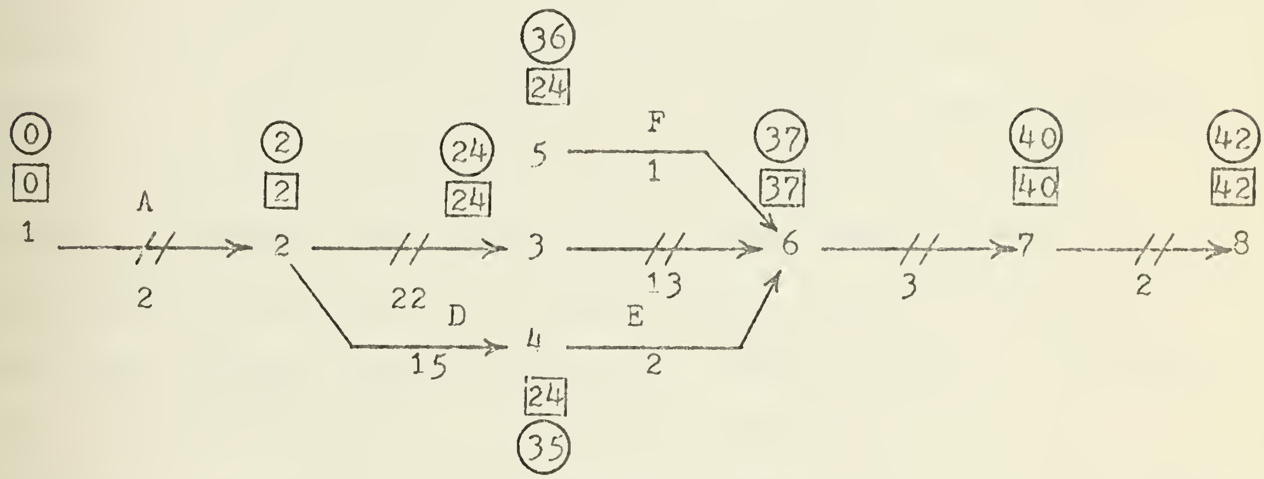

Figure 5 --- Arrow Diagram with Earliest and Latest Dates Shown

Armed with this information, the project manager can proceed to schedule the job. Once the start date is established, the start dates of each element on the "critical Path" can be fixed on the calendar. Start dates for other work elements may then be fixed to give the best utilization of resources, perhaps between projects as well as within the current one, by the scheduler.

The same basic process that was accomplished with the arrow diagram may be carried out utilizing a tabular format, inserting the dependency information into a computer program and utilizing the computer to determine all the computated factors. Another possible format is to utilize both the arrow diagram and the tabular layout with a computer. Use of a computer is almost mandatory on jobs of any complexity. Because the network is sometimes hard for construction tradesmen to grasp, a Gantt Chart portraying the schedule developed by CPM is usually prepared for use at the jobsite.[1]

Utilizing a CPM network, the project manager can tell immediately whether delays in various work elements will have an adverse effect on project completion or whether they can be absorbed in "float." By applying cost factors to each element, the contractor can predict his cash-flow requirements with accuracy. Assuming that the contractor and owner agree on a costed-out CPM network, the network may be used as a rational basis for contract progress payments. While defense contractors have consistently balked at a similar arrangement known as PERT/COST, preferring not to disclose such cost data outside their firms,[2] the Naval Facilities Engineering Command enjoyed a great deal of success with a pilot test project in the Southeastern United States. The system, known as "Construction Management Technique," was used by the contractors concerned to predict cash

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[1] Network Analysis for Construction Project Management, op. cit., p. 48.

[2] Peter P. Schoderbeck, op. cit., p. 447.

flow, by the Resident Officers in Charge of Construction to manage the overall job, and, by joint agreement, as the basis for contractor progress payments.

The degree to which CPM is utilized by National Capital Area construction firms and their rationale for its use are basic purposes of the present study.

Operations Research Techniques

In an editorial closing its 1963 publication on CPM, the construction industry journal, *Engineering News Record*, projected that contractors would adopt linear programming techniques as an extension of CPM in order to calculate the best way to allocate available men, equipment and materials among concurrent projects in the most profitable manner.[1] Linear Programming may be defined as:

> . . . a mathematical technique for finding the best uses of a firm's limited resources. The adjective *linear* is used to describe a relationship between two or more variables . . . which is directly and precisely proportional . . . *programming* refers to the use of certain mathematical techniques to get the best solution to a problem involving limited resources.[2]

Both CPM and PERT may be considered to fall within this definition.[3] However, the methods of which *Engineering News Record* spoke were the *Special-purpose algorithms*, which are "linear programming techniques useful when working with a certain

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[1]"CPM and Survival," *op. cit.*, p. 32.

[2]Richard I. Levin and Charles A. Kirkpatrick, *Quantitative Approaches to Management* (New York: McGraw-Hill Book Company, 1971), p. 161.

[3]James M. Antill, *Civil Engineering Management* (New York: American Elsevier Publishing Company, Inc., 1970), p. 16.

(specific) type of problem."[1] The two types usually mentioned when speaking of construction management are those allocation problems known as (1) "assignment problems" and (2) "transportation problems." Both are discussed in detail in many texts in the Operations Research field.[2]

In researching this paper, the writer found an almost total void in the construction management literature surveyed, which included not only texts on the subject, but the major construction periodicals also, on the subject of applications of linear programming and other operations research techniques to the construction industry. Neither Engineering News Record, The Constructor, or the American Society of Civil Engineers magazine, Civil Engineering shed light on this subject. Neither was he able to find illustrations in construction management texts written by American authors. Essentially identical, single examples of the two allocation techniques were found in a text written by a British author and another by an Australian.[3,4]

The present study examines the knowledge of and acceptance of linear programming techniques by the subject population.

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[1]Richard I. Levin, op. cit., p. 13.

[2]Ibid., p. 231-271.

[3]Roy Pilcher, Principles of Construction Management (London: McGraw-Hill, 1966), pp. 317-324.

[4]James M. Antill, op. cit., pp. 25-31.

CHAPTER III

CONDUCTING THE STUDY

Defining Modern Construction Project Management techniques

One of the first steps which was necessary before the study could be conducted was to select certain specific practices to be included in the category of "modern construction project management techniques." The writer has chosen the Second World War as the transition point to the "modern" period, primarily because it is generally agreed that the operations research disciplines from which most of the current group of project management techniques developed first coalesced.[1]

This definition excludes the Gantt Chart from the "modern" category. Considering that it has been in use more than half a century, this seemed altogether proper. Once the time frame for consideration had been established, a thorough search of the available construction management literature was selected as the most likely source for delineation of such techniques for the management of construction projects. This literature was sought from the library at George Washington University, from the libraries of military contracting agencies in the area, and from the AGC. The Naval School, Civil Engineer Corps Officers, which

[1]Richard I. Levin and Charles A. Kirkpatrick, op. cit., p. 7.

itself teaches a short course on construction management for officers ordered to Construction Battalions (Seabees), proved of great assistance in suggesting information sources and providing course literature.

The literature search identified the techniques discussed in Chapter II as those currently available for use by construction contractors. Telephone interviews with officials of both the AGC and the Construction Review Bureau of the Department of Commerce confirmed this view but pointed out a possible point of confusion in the usage of the term "construction management." The writer has used the term to mean the planning, organizing, staffing, controlling and directing of all effort concerned with a construction project. As with so many terms in the management field, "construction management" has begun to be used in a much narrower context by some to mean the hiring of a separate quality assurance firm to represent the customer for the purpose of assuring that the job is constructed in accordance with the design plans and specifications. This limited view of "construction management" has been spelled out by the AGC in one of its publications.[1]

In speaking of "construction management" the writer has maintained the broad, generalist and traditional interpretation throughout this paper.

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[1]The Associated General Contractors of America, <u>Construction Management Guidelines</u> (Washington, D. C.: The Associated General Contractors of America, 1972), pp. 1-10.

The Design of the Questionnaire

Once the techniques to be considered had been identified and the selection of the points on innovation diffusion theory to be utilized, as discussed in Chapter I, completed, a questionnaire to be administered by mail was designed. Emphasis was placed on making the questionnaire as easy and convenient as possible to fill out in an effort to increase response. A recent survey made of the 400 largest construction firms in the United States had produced only a thirty-five percent response,[1] and the writer had hoped to improve upon that figure in the present effort. Multiple choice questions requiring only a check by the respondent were used wherever possible, and blanks to be filled in provided where provision of an adequate range of multiple answers proved too cumbersome. A general section contained questions on the characteristics of the firm, such as size in terms of annual volume of construction, the ages and educational background of each firm's principal officers, primary customer sources and types of construction performed. Identical sections were then provided for each of the three modern project management techniques to be addressed. These contained questions to determine time of awareness and source, time of adoption and reason, continued use and reasons, and percent of jobs on which used.

At the request of NAVFAC contact points who are continuing the study of the pilot project mentioned in Chapter I, questions concerning the phases of project management on which the technique was used and the contributing components within the firm were added.

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[1]"Pitfalls of CPM," Constructor, September, 1972, p. 18.

A section on the Gantt Chart was added at the first of the questionnaire to measure the continued use of this technique and to give the firms a technique with which all were expected to be familiar as a starting point in filling out the questionnaire. It was hoped that this might help suppress bias in the return due to respondent unfamiliarity with the techniques surveyed. There was no expectation, however, that the actual adoption of the Gantt Chart could be analyzed since it had been in use for over half a century.

Appendix A is an example of the questionnaire used.

One consideration in the design of an anonymous questionnaire was to include some signature mechanism whereby the representativeness of the responding sample might be gauged. Two characteristics of the firms were examined in this respect. The first was the types of construction performed by the firms. Information was available from the AGC as to which types of specialized construction, or combination of these types, the individual firms had reported that they performed. By obtaining similar information on the questionnaire, it was expected that a measurement of the representativeness according to these functional groupings could be obtained. It was never expected, however, that a representative of every reported combination of construction types would be obtained, as there were a number of these identifiable with only one firm. Rather, a comparison of the sample with the population information figures on major specialties and combinations in general was planned.

The second characteristic to be considered in this respect was the annual volume of construction, which would give a gauge of firm size. Unfortunately, there was no information available as to the distribution of this factor over the population. Contacts with both the national and local governing bodies of the AGC established that this information was unobtainable for any but publicly-held firms. Nevertheless, these sources were able to provide a general expectation that there would be a relatively large concentration of firms at the lower end of a distribution by firm size, and that the population being examined contained firms ranging from the smaller firms to some doing business in the nine-figure range. Comparing the construction volume figures from the sample with this expectation was expected to yield a cross-check on representation by firm size.

Administering the Questionnaire

The names and addresses of all of the membership of the AGC who operate in the National Capital Area were obtained from the national headquarters of the AGC. In preparing to mail the questionnaires to these firms, stamped self-addressed envelopes were made up in which they could return the forms. This effort was performed for the purpose of increasing response. All of the questionnaires were mailed, with an accompanying letter, on the same day. Response began almost immediately, with almost thirty percent of the final response received within the first week. Response then tapered off, the final considered by the paper being received in the fifth week after initial mailing to the firms.

Twenty-seven firms responded to the questionnaire, giving a sample of fifty-two percent of the target population. Appendix B is a listing of the firms to whom the questionnaire was sent.

<u>Representativeness of the Sample</u>

A good distribution by functional stratification was obtained within the sample, although slightly weighted in favor of diversified as opposed to specialized firms. The fifty-two firm population split seventy-seven percent specialized and twenty-three percent diversified, whereas the sample split seventy percent and thirty percent, respectively. The significance of subgroupings by combinations under the diversified group was called into question by the fact that half these firms responding gave answers differing from the information they had previously provided AGC concerning types of construction performed. However, these were identified as to parallel categorization with population data by firm mail stamps.

The sample results were, within the specialized category, somewhat weighted in favor of heavy construction as opposed to building construction. The population percentages for these categories were 67.3 and 7.6, respectively, while those for the sample were 55.6 and 14.8 percent. The single firm in the population which reported highway specialization did not reply to the questionnaire. This was not considered significant as the AGC reported that this firm had opened a Washington office primarily for a single, large project they had underway, and that they were therefore not normally a part of the local construction community. Overall, the various functional segments

of the construction community were well represented in the sample, and bearing in mind the biases discussed above, their distribution was satisfactory.

The distribution of firms by volume of construction reported in the sample was also satisfactory. As expected, there was a concentration of firms at the lower end of the construction volume distribution, and firms of varying sizes up the nine-figure range were represented. Details of the distribution are discussed in a subsequent chapter. The precision of knowledge concerning the distribution of this factor in the target population was not great enough to allow an estimate of bias.

CHAPTER IV

RESULTS OF THE STUDY

General Description of the Results

As previously noted, twenty-seven members of the AGC completed and returned the questionnaires. In some cases, however, the questions were not all completely answered, so that in interpreting the results, calculations have been based on the number completing each question.

Some of the characteristics of the responding firms vary widely while others are surprisingly consistent. The first characteristic addressed by the questionnaire was the size of the firm in terms of the annual dollar volume of construction, a measurement primarily for sample stratification purposes, as discussed in Chapter III. The mean volume of construction of the responding firms, based on the twenty-six who answered this question, was fifty-five million dollars, with a standard deviation of $136 million. This very large standard deviation was caused by the fact that eighty-two percent of the total volume of all the firms was performed by the largest four firms, with over forty-two percent reported by the single largest firm. The general spread of construction volume is shown in Figure 6 and Figure 7.

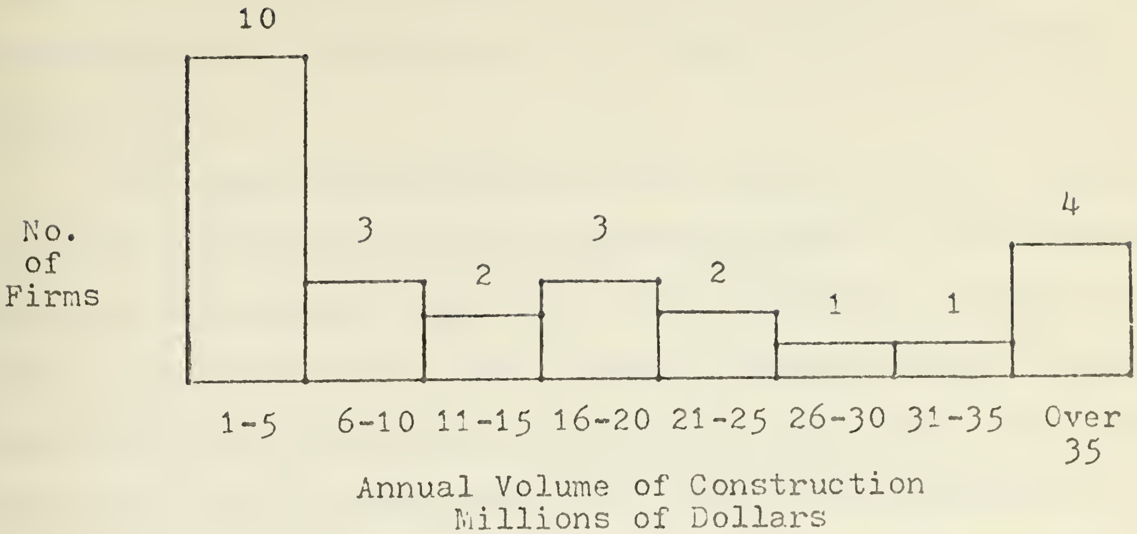


Figure 6 --- Numbers of Firms by Volume Category

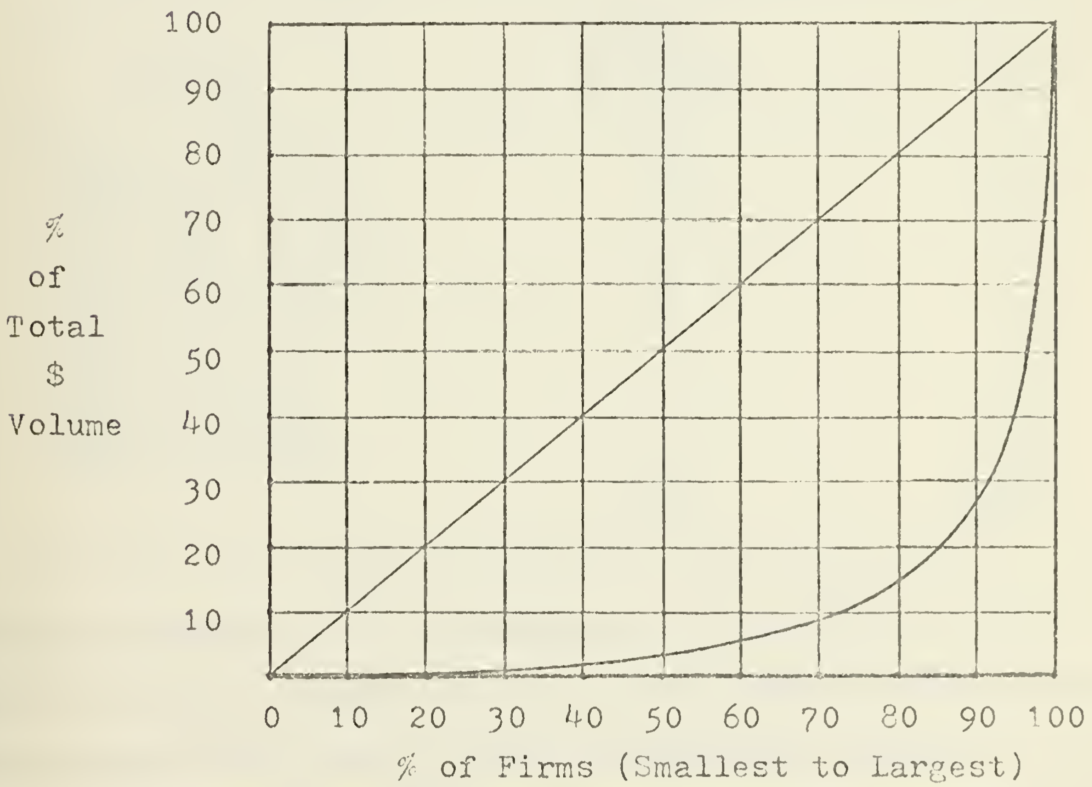


Figure 7 --- Distribution of Annual Dollar Volume
Among Sample Firms.

Figure 6 shows the number of firms reporting annual volumes of construction within the ranges shown, while Figure 7 shows the concentration of a majority of the dollar volume in the few largest firms.

The next characteristic to be examined was the types of construction performed by the responding firms. This characteristic was the primary signature device employed. It was of direct pertinence to the basic study in testing Rogers' postulation that early adopters of innovations have more specialized operations than do later adopters. Table 2 is a summary of this information. Building construction was by far the largest

TABLE 2

NUMBERS OF FIRMS BY TYPES OF CONSTRUCTION PERFORMED

Construction Type Category	Number of Firms	Percent of Sample
Building Only	15	55.6
Highway (HW) Only	0	0
Heavy (HE) Only	4	14.8
Utilities (U) Only	1	3.7
Railroads (R) Only	0	0
Mixed, B & HE	2	7.4
Mixed, B, HE & U	1	3.7
Mixed, HW, HE, U & R	1	3.7
Mixed, HE & U	1	3.7
Mixed, HW & HE	1	3.7
Mixed, All Types	1	3.7
	27	100.0

category reported, with 55.6 percent of the sample in terms of numbers of firms engaged solely in this type of construction with an additional eleven percent reporting a combination of building and other types. The "building only" category includes the largest firm reporting and the fourth largest, while the

mixed categories which include building construction contained the other two of the four largest firms. Building construction was clearly the most important category within the sample considered, both in terms of number of firms involved and in terms of construction volume.

The responding firms also reported their primary customer sources. This information was part of the data requested by NAVFAC for comparison with their study and was also of use to compare public and private owner requirements. Those provided for by the questionnaire were "Federal Government," "State and Local Government" and "Private Sources." The firms responded as shown in Table 3. The private sector was by far the most important source reported, with over forty-eight percent of the firms

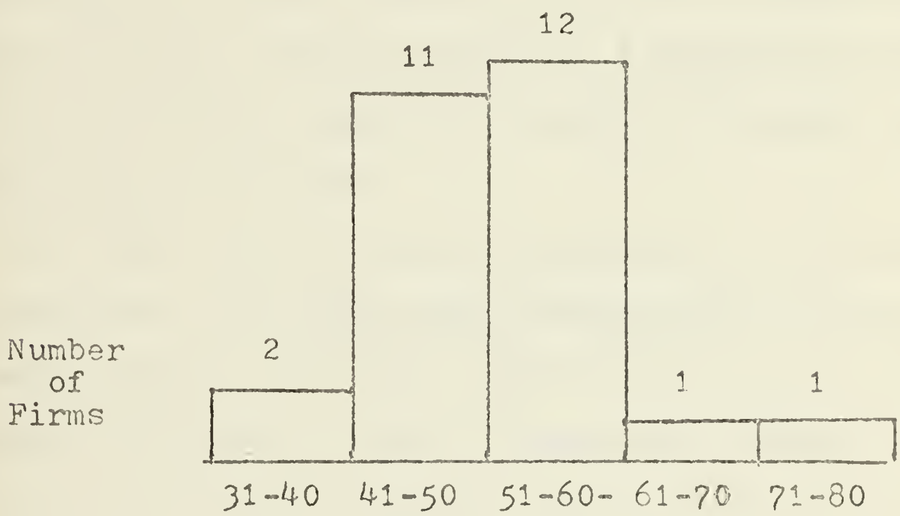
TABLE 3

NUMBERS OF FIRMS BY CUSTOMER SOURCES

Customer Source	Number of Firms	Percent of Sample
Federal Government (F)	4	14.8
State and Local Government (S & L)	3	11.2
Private Sources (P)	13	48.1
Mixed, F, S&L	4	14.8
Mixed, F & P	1	3.7
Mixed, P, S&L	2	7.4
	27	100.0

reporting that their businesses were primarily supported by private funding. In terms of dollar volume of construction, over eighty-five percent of the total volume reported by the responding firms (1218.5 of 1423.5 million dollars) was attributible to firms indicating "private sources" as their primary customers.

Information was obtained on the ages of the principal officers of the responding firms. This information was used to test Rogers' theory that early adopters are younger in age than later adopters. Where a firm reported more than one principal officer, the ages of those reported were averaged to obtain a mean age for each firm, and these firm mean ages were used in calculating the aggregate statistics for the twenty-seven firm sample. Figure 8 shows the age distribution of the principal officers of the firms reporting. The mean age for the overall sample was 50.4 years, with a standard deviation of 7.9 years.



Age of Principal Officers in Years

Figure 8 --- Age Distribution of Principal Officers of Firms.

Another characteristic examined was the educational background of the principal officers of the reporting firms. Table 4 shows these results. This is the characteristic in which the firms are most closely alike, with the vast majority educated to the bachelor's degree level. With only one principal

TABLE 4

EDUCATIONAL LEVEL OF FIRMS' PRINCIPAL OFFICERS

Educational Level	Number of Firms	Percent of Sample
No College Degree (N)	1	3.7
Bachelors Degree (B)	24	88.9
Advanced Degree (A)	0	0
Mixed, N & B	1	3.7
Mixed, B & A	1	3.7
	27	100.0

officer reporting a degree beyond the bachelor level and only two reporting no college degree at all, the initial intent to attempt to use this characteristic as a measure of relative social status between members of adopter categories (page 11) was essentially frustrated.

The last general question addressed to the responding firms concerned their principal criteria for selecting a project management technique for each construction project, another measurement for NAVFAC. Table 5 shows the reported information. Note that two of the respondents failed to answer this question.

TABLE 5

CRITERIA FOR SELECTING PROJECT MANAGEMENT TECHNIQUES

Principal Criteria for Selecting Technique	Number of Firms	Percent of Sample
Job Size	1	4.0
Job Complexity	3	12.0
Job Size and Job Complexity	17	68.0
Use Same for All Jobs	2	8.0
Specifications of Customers	2	8.0
	25	100.0

The percentage figures contained in the table are calculated on the basis of the number who answered the question, twenty-five. The combination of job size and job complexity was by far the predominant answer. Job complexity was the next most important factor. The two firms which indicated that they used the same technique for all jobs both reported that they used CPM. Only two firms indicated in this section that their principal criteria for project management technique was the requirements set by their customers.

The evidence of this study suggests that the "average" construction contractor in the National Capital Area is approximately fifty years of age, educated to the bachelor degree level, and engaged primarily in building construction funded primarily by private sources.

Project Management Techniques In Use by the Respondents

The questionnaire results indicate that both the Gantt Chart and CPM are in wide use among the respondents. As discussed in Chapter III, the Gantt Chart was included in the questionnaire primarily as a check on its continued use and to give the contractors a section of the questionnaire on a technique with which all were expected to be familiar as a starting point to get used to the format and questions. There was no intention to try to compare data on this technique with the points of Rogers' innovation diffusion theory as it was expected that the technique had been adopted by the construction industry such a long time in the past that current contractors might not have even been

in business at the time its adoption occurred. The data on this technique, however, proved quite interesting, and a detailed analysis is presented in a later part of this chapter.

Use of CPM was indicated by twenty-six of the twenty-seven firms. As expected, the firms were able to provide the detailed information requested on the timing and reasons for their adoption of this technique. An analysis of this data with a comparison of the selected portions of innovation diffusion theory with the results is presented later in the chapter.

The results concerning the utilization of the Line of Balance and the various Linear Programming techniques were disappointing. Only two firms indicated that they had an awareness of the Linear Programming techniques. All twenty-seven firms indicated that they were not aware of the Line of Balance technique. None of the firms indicated that they had ever used either. The analysis that could be performed considering both these techniques was therefore extremely limited.

Detailed Results Concerning the Gantt Chart

All twenty-seven firms provided information concerning their use of the Gantt Chart. Nineteen indicated that they had employed the technique, of which four reported that they had used electronic computers in this connection while fifteen had not. Only seventeen of the twenty-seven responding firms indicated that they still use the Gantt Chart. Eight respondents reported that they had never used this technique. All of these quoted unawareness of the technique or unfamiliarity with its use as

their primary reason for non-utilization. Two of the firms which had used the Gantt Chart reported that they had discontinued its use in favor of CPM. These were the same two firms which reported that they used the same project management techniques on all their jobs. The seventeen firms that indicated that they are still using Gantt's bar chart as a project management tool represent only sixty-three percent of the responding firms. Considering the suggestion of Deatherage[1] that most contractors would choose to use a bar chart even when more sophisticated techniques were also utilized, this figure seemed surprisingly small to the writer. Statistically, it could be stated with ninety-five percent certainty that the percent of the total population still using the Gantt Chart lies between forty-two percent and eighty percent. Another possibility which cannot be totally ignored is that some of the firms that indicated a lack of awareness of this technique are in fact using it, but call it by some other term than "Bar (Gantt) Chart," which was the terminology utilized in the questionnaire.

Fifteen of the seventeen firms which reported continued use of the Gantt Chart answered the questions concerning the breadth and reasons for its use. Table 6 shows the reasons given for continued use of the Gantt Chart. It should be noted that almost half those firms still using the Gantt Chart indicated that they do so because their customers require them to. The factor of contractual coercion appears to be a substantial factor in the continued use of this technique. This factor

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[1]George E. Deatherage, op. cit., p. 30.

appeared as a major factor throughout the study when considering the reasons why contractors adopt and perpetuate the use of various project management techniques.

TABLE 6

PRIMARY REASONS FOR CONTINUING USE OF GANTT CHART

Reason	Number of Firms	Percent of Answering Firms
Allows Better Control of Job	5	33.3
Both Increased Profit and Better Job Control	2	13.3
Required by Owners (Contracting Agencies)	7	46.7
Easy for Craftsmen to Understand	1	6.7
	15	100.0

Table 7 shows the scope of use of the Gantt Chart indicated by the firms, in terms of the approximate percentage of their jobs on which the technique is used. The table indicates a fairly wide spread of use scope by the reporting firms. The weighted average utilization by these firms suggests that, in aggregate, they use the Gantt Chart on some sixty-one percent of

TABLE 7

APPROXIMATE PERCENTAGES OF JOBS ON WHICH GANTT CHARTS ARE USED

Approximate Percent of Jobs On Which Gantt Charts Used	Number of Firms	Percent of Answering Firms
1-20	2	13.3
21-40	3	20.0
41-60	2	13.3
61-80	3	20.0
81-99	1	6.7
100	4	26.7
	15	100.0

their jobs. Considering that sixty-three percent of the sample indicated that they use the technique, a further weighting would suggest that the reporting firms use this technique on some thirty-eight percent of all jobs.

The firms were also requested to provide information concerning which phases of construction management they utilized the various techniques and concerning the contributors of inputs to use of the techniques. As noted in Chapter I, these questions were of interest to NAVFAC for correlation with a similar but more limited study. Table 8 contains information on which phases of construction management the fifteen firms answering utilize the Gantt Chart, while Table 9 indicates the spread of contributors of inputs. It should be noted that since firms provided multiple answers to these questions, the percentage figures will not add to 100.

TABLE 8

USE OF GANTT CHARTS IN PHASES OF CONSTRUCTION MANAGEMENT

Construction Management Phase	Firms Employing Gantt Chart	Percent of Answering Firms
Planning	9	60.0
Scheduling	14	93.3
Monitoring Progress	13	86.7
Cost Collection	5	33.3
Resource Allocation	2	13.3
Payment Requests	9	60.0

TABLE 9

INPUT CONTRIBUTORS TO USE OF GANTT CHARTS

Potential Input Contributors	Firms Employing Gantt Chart	Percent of Answering Firms
Job-site Supervisors	10	66.7
Project Manager	13	86.7
Estimators	7	46.7
Purchasing Department	2	13.3
Subcontractors	6	40.0
Top Management	10	66.7

Detailed Results Concerning The Critical Path Method

Of the twenty-seven firms which replied to the questionnaire, twenty-six reported that they had adopted CPM. This represented an adoption rate in excess of ninety-six percent. One firm reported that it had discontinued use of CPM. Two of the firms that reported using CPM unfortunately failed to report some of the requested information concerning initial awareness of the technique and initial adoption time, so many of the results must be reported on the basis of the other twenty-four firms. For these, a full range of survey data is available for analysis.

First to be discussed will be the questions of diffusion of awareness concerning the technique and the relative rate of adoption over time. A point which must be immediately addressed is the fact that two of the firms reported knowledge of the technique at times earlier than the generally-accepted date for completion of its development, 1956.[1] One of these cited sources outside the construction industry for his awareness while the other cited printed literature. Since PERT and CPM were under development during this period, it is not beyond the realm of possibility that these contractors became aware of the techniques before the details of their use became general knowledge. The writer has chosen to accept the responding firms' claims and to base the statistics to be discussed on their inclusion. Table 10 is a cross-tabulation portraying the distributions of awareness and adoption of CPM over time as reported by the twenty-four firms responding to the question. The mean figure of years to become

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[1]George E. Deatherage, op. cit., p. 30.

TABLE 10

DISTRIBUTION OF AWARENESS OF CPM AND ADOPTION OF CPM OVER TIME BY NUMBERS OF FIRMS

Years to Awareness From 1956	Years to Adoption from 1956									
	(-2)-(-1)	0-1	2-3	4-5	6-7	8-9	10-11	12-13	14-15	Total
-4--3			1							1
-2--1	1									1
0-1				2						2
2-3										0
4-5				2	1					3
6-7					5	1	2			8
8-9						4	1			5
10-11							1	1		2
12-13								1	1	2
Total	1	0	1	4	6	5	4	2	1	24

aware of CPM for the twenty-four firms was 6.25 years with a standard deviation of 4.1 years while the mean time to adopt CPM was 7.6 years with a standard deviation of 3.57 years. Simultaneous awareness and adoption occurred in thirteen of the twenty-four cases, or fifty-four percent of the cases. The reasons for this coincidence of awareness and adoption is discussed later in this section.

Rogers categorizes adopters of innovations on the basis of time of adoption. Figure 9 portrays his basic categorization criteria.[1] Those whose time of adoption fall more than two standard deviations to the left of the mean, or the first 2½ percent of the adopters, he terms "innovators" (I). Those whose time of adoption falls between one and two standard deviations to the left of the mean, the next 13½ percent, he terms "early adopters" (EA). Those with an adoption time within one standard deviation to the left of the mean, which includes the next 34 percent, he labels "early majority" (EM). Those who fall within one standard deviation to the right of the mean are termed "late

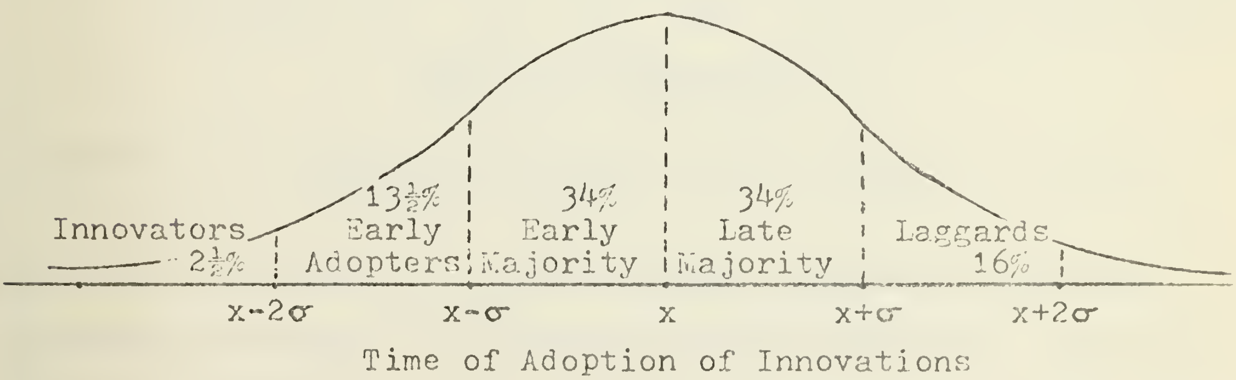

Figure 9 --- Adopter Categorization on the Basis of Relative Time of Adoption of Innovations According to Rogers.

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[1]Everett M. Rogers, op. cit., p. 162.

majority" (LM), a category which also includes 34 percent of the adopters. Those whose time of adoption is greater than one standard deviation to the right of the mean, he calls "laggards" (L). It should be noted that all of the percentage figures above assume a normal distribution.

The first of Rogers' generalizations may now be addressed.

Adopter distributions follow a bell-shaped curve over time and approach normality. Figure 10 indicates that the adoption of CPM by the reporting firms did follow a bell-shaped curve over time. Comparison of the percentages of the firms falling within the standard deviation groupings utilized in Figure 9, however, shows that the curve for the sample is skewed slightly to the right of a normal distribution. The twenty-four

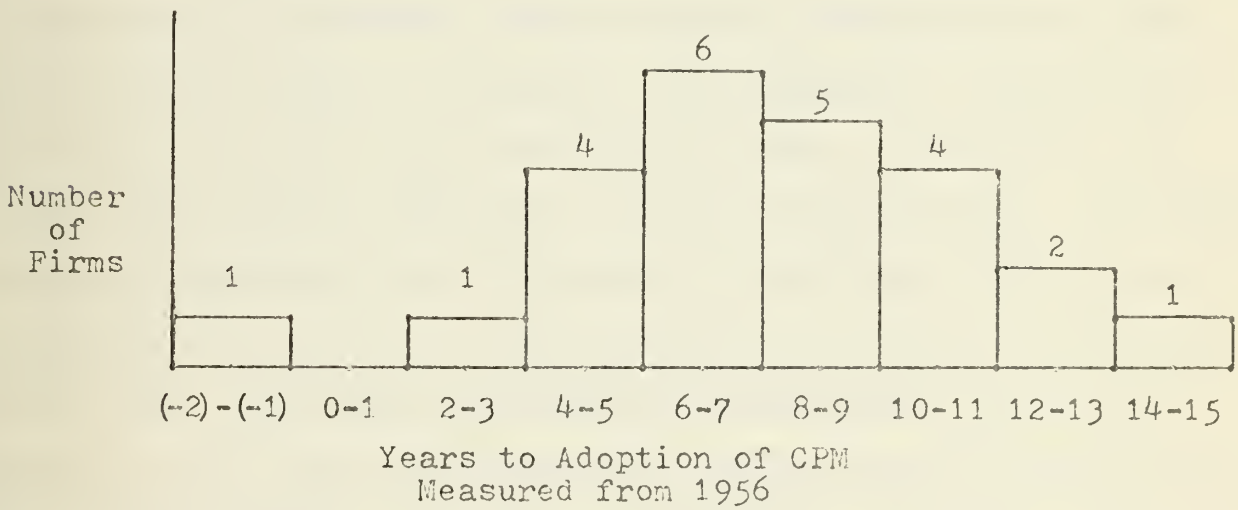

Figure 10 --- Distribution Over Time of Adoption of CPM by Responding Firms.

firms were categorized adopting Rogers" category titles and groupings according to standard deviation location. Table 11 shows the comparison of the results of this grouping with those of Figure 10. The "innovator" category contains a firm which

TABLE 11

COMPARISON OF CPM ADOPTION DISTRIBUTION
WITH NORMAL DISTRIBUTION

Adoption Category	Number of Firms	Percent of Firms	Percent of Firms by Normal Distribution
Innovators (I)	1	4.2	2.5
Early Adopters (EA)	4	16.6	13.5
Early Majority (EM)	7	29.2	34.0
Late Majority (LM)	9	37.5	34.0
Laggards (L)	3	12.5	16.0
		100.0	100.0

reported adopting CPM in 1954. The "early adopter" category contains one firm that took three years to adoption and three which took four. The "early majority" category contains firms which reported five, six or seven years to adoption, while the "late majority" category contains firms reporting eight, nine, ten or eleven years to adoption. The "laggards" category was made up of one firm which took twelve years to adoption, one which took thirteen years and one which took fourteen. Following Rogers' suggestion, the firm which had not adopted CPM was not classified.[1] None of the firms reported an adoption date later than 1970. While the CPM adoption distribution curve climbs faster in the first two categories than the normal distribution and does not fall away from the value at the mean during the "late majority" category, its shape is similar to the normal, and the areas under the curve on either side of the mean are essentially equal. The results of this study therefore suggest

[1]Everett M. Rogers, op. cit., p. 165.

that Rogers' generalization concerning the shape of the innovation distribution curve was true in the case of the adoption of CPM by the AGC in the National Capital Area.

Before proceeding to examine other generalizations concerning the adoption of CPM, the data provided by the survey concerning sources of awareness and reasons for adoption must be examined. Table 12 is a matrix showing the number of firms in each adopter category by initial awareness source. Table 13

TABLE 12

NUMBERS OF FIRMS IN ADOPTER CATEGORIES
BY SOURCE OF AWARENESS OF CPM

Sources of Awareness	Adopter Categories					
	I	EA	EM	LM	L	Total
Printed Literature		1	1			2
Fellow Contractors				1	1	2
Industry Presentations		1	2	4		7
Non-industry Formal Presentation		2		1		3
Owner (Contracting Agency) Requirements			3	3	2	8
Other Non-construction Industry	1		1			2
Totals	1	4	7	9	3	24

is a matrix showing the number of firms in each adopter category by their primary prompters to adoption of CPM. This data suggests that the factor of contractual coercion was a most important driving factor in the adoption of CPM by the respondents, with

TABLE 13

NUMBERS OF FIRMS IN ADOPTER CATEGORIES BY WHAT PRIMARILY LED THEM TO FIRST ADOPT CPM

Prompters to Adoption	Adopter Categories					
	I	EA	EM	LM	L	Total
Printed Literature		1	1			2
Fellow Contractors						0
Industry Presentations		1	1	2		4
Non-industry Formal Presentations		1	1			2
Owner (Contracting Agency) Requirements		1	4	7	3	15
Other Non-construction Industry Sources	1					1
Totals	1	4	7	9	3	24

one-third indicating that they first heard of the technique from owner requirements and almost two-thirds indicating that they first adopted it because of owner requirements.

Others of Rogers' generalizations are next compared with the data concerning the adoption of CPM.

Awareness occurs at a more rapid rate than does adoption. An examination of Table 10 along with the accompanying data on means and standard deviations supports this generalization as far as the adoption of CPM by the respondents is concerned. The mean figures indicate an average lag from awareness to adoption of over one year. However, this average is a good example of how misleading raw averages by themselves can be. Over fifty percent (thirteen of twenty-four) reported learning of and adopting CPM in the same year, while the difference between awareness and adoption varied up to six years among the other firms. The evidence suggests that the very short mean difference

between awareness and adoption of CPM was caused by the already emphasized factor of contractual coercion by the customers of the contractors. The spread between awareness and adoption might otherwise have been much greater.

Cosmopolite sources of information are more important than localite sources for relatively early adopters of innovations than for later adopters. The data in Table 12 tends to support this contention as far as initial awareness of CPM by the respondents is concerned. The categories "printed literature," "non-industry formal presentations" and "other non-construction industry sources" are interpreted by the writer to be cosmopolite sources. The "innovator" cited the latter of these. Three of the four "early adopters" cited the other two. Two of the seven firms in the "early majority" category cited one or the other of these sources. Only one of the twelve firms in the last fifty percent of the adopters cited any of these sources. A similar and just as strong analogy can be drawn with the adoption factors from Table 13. Despite the factor of owner coercion, almost half the adoptions in the early categories were prompted by cosmopolite sources.

Cosmopolite information sources are most important at the awareness stage and localite information sources are more important at the evaluation stage. The data from Table 12 and Table 13 does not appear to support this contention. Cosmopolite sources were, as discussed in the previous section, found to be of primary importance in initial awareness of CPM and also predominant in prompting adoption in five cases. The balance in

influence between cosmopolite and localite sources were essentially equal in the two cases as far as the questionnaire respondents were concerned.

Earlier adopters utilize information sources that are in closer contact with the origin of new ideas than late adopters. There is some evidence to support this contention in the questionnaire data. The first two firms to learn of CPM reported that they did so in 1953 and 1954 from, unfortunately anonymous, sources outside the construction industry. One of these was the "innovator" and the other the earliest of the "early adopters." The latter reported his source of awareness was a formal presentation by a source outside the construction industry (the questionnaire used a college course as am example of this category), as also did a second "early adopter" who reported learning of CPM in 1956. A third "early adopter" reported learning of CPM from printed literature in 1960. The fourth "early adopter" learned of CPM in 1960 from a formal construction industry presentation (AGC meetings were used as an example of this category in the questionnaire). All other reported sources of awareness beyond this point were from within the construction industry except one of the "early majority" who cited printed literature as his source. Four of the first five firms to adopt CPM thus learned of CPM from sources which can be interpreted to be relatively closer to the origin of the idea. This represents 16.7 percent of the reporting firms. Three of these firms reported the same source as the primary prompter to actual adoption of the technique.

Impersonal sources of information are more important than personal sources for relatively early adopters of innovations than for later adopters. Personal influence from peers is more important for relatively late adopters than for early adopters. These two generalizations do not appear to be supported by the questionnaire data, primarily because personal or peer group sources and influences play such a small part in the response. Only two firms cited fellow contractors as their source of awareness of CPM and none cited influence from fellow contractors as a prompter to adoption. Whether the "innovator" had a personal or impersonal source outside the construction industry is moot. All the other sources and prompters are essentially impersonal. Again, the key role played by contractual coercion from customers predominates the issue.

Early adopters are younger in age than later adopters. The information provided by respondent firms on the ages of their principal officers did not support this contention. In fact, a case could be made from the data of the exact opposite, that the early adopters are older.

In the section dealing with the Gantt Chart, it was pointed out that the overall mean age of principal officers of the responding firms was 50.4 years with a standard deviation of 7.9 years. Table 14 contains the age means and standard deviations for the firms in each of the adopter categories. Viewed on this basis, longevity tips towards the relatively earlier adopters, but just slightly.

TABLE 14

AGE MEANS AND STANDARD DEVIATIONS FOR FIRMS IN ADOPTER CATEGORIES

Adopter Category	Mean Principal Officer Age	Age Standard Deviation
Innovator	55.5	0
Early Adopters	47.5	3.4
Early Majority	52.6	12.9
Late Majority	48.9	6.5
Laggards	48.8	5.8

Aggregating the figures gives a somewhat clearer picture. If "innovator" and "early adopters" are combined, their resultant mean age is 49.1 years. Further inclusion of the "early majority" in this figure to obtain a mean age for the first fifty percent of the adopting firms yields a mean age of 51.1 years, which compares with a mean of 48.9 years for the last fifty percent.

It may be noted that deleting the effects of the single septuagenarian from the "early majority" category yields an aggregate mean age for the "early" half of 48.95 years, almost identical to that for the "late" half. Age does not appear to have been a significant factor in the adoption of CPM by the responding firms.

Early adopters have more specialized operations than late adopters. Table 15 has been constructed to aid in addressing this question. The numbers of firms in each adopter category are shown according to the types of construction which they reported that they performed. The evidence in Table 15 tends

TABLE 15

NUMBERS OF FIRMS IN ADOPTER CATEGORIES
BY TYPES OF CONSTRUCTION PERFORMED

Types of Construction	Adopter Categories					
	I	EA	EM	LM	L	Total
Building (B) Only	1	4	3	2	2	12
Highway (HW) Only						0
Heavy (HE) Only			1	3		4
Utilities (U) Only			1			1
Railroads (R) Only						0
Mixed (B & HE)			1	1		2
Mixed (B, HE & U)				1		1
Mixed (HE & U)			1			1
Mixed (HW & HE)				1		1
Mixed (HW, HE, U & R)				1		1
Mixed (All Types)					1	1
Total	1	4	7	9	3	24

to support this generalization. Of the first fifty percent of the adopters, only two of twelve did not have specialized operations. Of the seven firms reporting mixed operations, five fell in the "late majority" or "laggard" categories.

The question of whether significant numbers of contractors have now accepted CPM because of its effectiveness as opposed to being coerced to its use was examined. Referring again to Table 13, fifteen of the twenty-four firms stated that they originally adopted CPM because of owner requirements. This included all of the "laggards" and seven of the nine "late majority" firms. Four of the seven "early majority" firms reported similar motivations in adopting CPM as did one of the

"early adopter" firms. Only in the cases of the "innovator" and "early adopter" categories was not customer coercion the overwhelmingly predominant factor in adoption of CPM.

Firms were also asked to note their primary reason for continuing to use CPM. Table 16 shows the answers, segregated by adopter category. Since one of the "early adopter" firms reported discontinuing the use of CPM and one of the "late majority" firms did not answer this question, Table 16 is constructed on the basis of twenty-two responding firms. A comparison of Table 16 with Table 13 indicates a shift toward

TABLE 16

REASONS FOR CONTINUING USE OF CPM
BY FIRMS IN ADOPTER CATEGORIES

Reasons for Continuing	Adopter Categories					
	I	EA	EM	LM	L	Total
Increased Profits						0
Better Job Control		2	3	2	1	8
More Accurate Bids						0
Better Profit and Job Control	1		2	1		4
Required by Owners (Contracting Agency)		1	2	5	2	10
Total	1	3	7	8	3	22

economic factors as opposed to coercive ones between initial adoption and continued use of CPM. Only 43.5 percent of the respondents indicated customer requirements as the reason for continued use as opposed to 62.5 percent who gave that factor as their original reason for adoption. Those who indicated economic reasons for adoption also indicated economic reasons for continuing, with the exception of the one firm which stopped

using CPM. Of the four "early majority" firms which indicated customer requirements as the reason for adoption, two shifted to economic reasons for retaining. One of the "late majority" firms switched to economic reasons while one failed to answer the question. Also, one of the "laggard" firms also switched to economic reasons for continued use. It is, however, strongly suggested by these results that the contractual coercion factor is still the single most important factor in the use of CPM. This is true both in government and private construction. Of the fifteen firms reporting owner requirements as the reason for adoption, six work solely in the private sector, two solely on state and local government work, two solely on federal government work, one each on combinations of federal government and private work and on private and state and local government work, and three reported combinations of federal and state and local government work. Of the ten firms reporting continued use of CPM because of customer requirements, three work solely for private sources, three solely for state and local government, two for combinations of federal and state and local government, one for combined private and federal government sources and one for combined private and state and local government sources.

The remaining subsidiary research question to be addressed is the question of what factors, if any, have given impetus to the use of CPM in the recent past. One is tempted to conclude that the answer to this question is "none." The writer had expected to find that the economic pressures on the construction industry brought on by the economic recession of

1969-1970 had led some construction firms to adoption of more modern project management techniques. CPM had, however, been essentially adopted by the responding firms before these events occurred. The most potent factor bringing the latter half of the firms to adopt CPM has been shown to be contractual coercion, with over eighty-three percent of the firms adopting after the mean adoption year citing this reason.

Table 17 shows the approximate percentages of jobs on which CPM is used by firms in each adopter category. This table

TABLE 17

REPORTED UTILIZATION OF CPM

Approximate Percentage Of Jobs	No. of Firms by Adopter Categories				
	I	EA	EM	LM	L	Total
1-20		1	2	1	2	6
21-40	1	1		2		4
41-60			2	3		5
61-80		1	1		1	3
81-99			1	2		3
All			1			1
Total	1	3	7	8	3	22

is also constructed on the basis of twenty-two respondents. The figures in Table 17 indicate a mean useage among these firms of 46.3 percent of their jobs managed by CPM. If further weighted by the fact that twenty-five of twenty-seven responding firms reported that they are using CPM, this suggests that approximately 42.8 percent of the jobs performed by the responding firms are managed by CPM.

Table 18 and Table 19 contain the data collected for use in the parallel NAVFAC study. Again, these tables are based on the twenty-two firms who answered the requisite questions.

TABLE 18

USE OF CPM IN PHASES OF CONSTRUCTION MANAGEMENT

Construction Management Phase	Firms Employing CPM	Percent of Firms
Planning	14	63.6
Scheduling	22	100.0
Monitoring Progress	13	59.1
Cost Collection	5	22.7
Resource Allocation	1	4.5
Payment Requests	9	40.9

TABLE 19

CONTRIBUTORS TO USE OF CPM

Potential Input Contributors	Firms Employing Contributor	Percent of Firms
Job-site Supervisors	14	63.6
Project Manager	21	95.5
Outside Consultants	7	33.3
Estimators	9	40.9
Purchasing Department	6	27.3
Subcontractors	14	63.6
Top Management	13	59.1

Detailed Results Concerning The Line of Balance Technique

All twenty-seven firms which returned questionnaires responded that they did not use the Line of Balance technique and that they had never used it because they were unaware of it or unfamiliar with its use. This indicates that this technique has achieved no significant adoption among National Capital Area construction firms and that they are, in fact, unaware of its existence. No further analysis is possible from the data available.

Detailed Results Concerning Linear Programming Techniques

Twenty-five of the twenty-seven responding firms indicated that they were unaware of or unfamiliar with the use of linear programming techniques. Of the two who indicated an awareness, both replied that they had never employed these techniques because they considered them both too costly and too complex. This indicates that while some slight awareness of linear programming techniques exists in the area construction industry, little, if any, adoption has occurred.

CHAPTER V

CONCLUSIONS

The purpose of this study was to ascertain whether significant use was being made of modern construction project management techniques by construction contractors in the area of Washington, D. C., and its environs. Chapter II surveyed the subject of modern construction project management techniques, identifying the Critical Path Method, Line of Balance, and certain Linear Programming Techniques as the methods to be studied. Chapter III described how the study was conducted, and Chapter IV presented the results of the study.

In considering the results of the study, the slight proportional biases in the sample when compared to the population should be recalled. The sample was slightly more weighted towards diversified as opposed to specialized construction than the population. It was also slightly more weighted towards heavy construction as opposed to building construction. These biases were not considered great enough to have significantly altered the study results.

Before addressing the primary research question, each of the subsidiary research questions are discussed.

<u>What are modern construction project management techniques as delineated in the literature of construction management?</u>

Modern construction project management techniques were identified in Chapter II and Chapter III as CPM, LOB and Linear Programming Techniques, principally the "assignment problem" and the "transportation problem."

<u>To what extent are the above techniques in use, and what are the distributions of their adoption over time?</u>

This study revealed no use at all of LOB or of Linear Programming Techniques among the respondents to the questionnaire. The study indicates that the adoption of these techniques has not yet begun in the target population. CPM, on the other hand, was found in use among twenty-five of the twenty-seven responding firms, with one of the firms not using it indicating an earlier trial and discontinuance. Mean time to adoption was found to be 7.6 years from 1956, with a standard deviation of 3.57 years. By means of weighted averages, it was estimated that CPM was used on approximately 42.8 percent of the construction projects performed by the responding firms.

Seventeen of the twenty-seven firms indicated that they still utilize the Gantt Chart. By means of weighted averages, it was estimated that this technique is employed on some 38.0 percent of the construction projects performed by the responding firms.

Most of the firms (68.0%) indicated that they selected a project management technique on the basis of a combination of job size and job complexity.

Have a significant number of contractors accepted modern project management techniques because of their expected or proven effectiveness as opposed to being coerced to their use by their customers?

As far as LOB and Linear Programming Techniques are concerned, the study suggests that the target population has not accepted these techniques for these or any other reasons. Concerning CPM, economic considerations were important in the adoption process only for the "innovator" and "early adopter" categories. Ten of the last twelve firms to adopt CPM did so because of customer coercion. However, this factor fell to less than fifty percent of responses as far as the reasons for continued use of CPM were concerned, with economic considerations dominating in this case. There is reason to believe from the evidence that contractors are now accepting CPM for its proven effectiveness.

What factors, if any, have given impetus to the use of modern project management techniques in the recent past?

The only factor identified by the study to have affected the use of the study techniques was customer coercion for the use of CPM. Since no adoptions of CPM were reported later than 1970, no factors seem to have given any impetus in the very recent past.

What were selected characteristics of contractors in the various adopter categories as compared to those predicted by Rogers?

In the case of CPM among the study group, awareness preceded adoption by more than one year in eleven of twenty-four cases. The other thirteen both learned of and adopted CPM in the same year. The factor of customer coercion had a strong influence on both events.

Cosmopolite sources of information are more important than localite sources for relatively early adopters of innovations than for later adopters.

The evidence of this study tends to support this contention, with cosmopolite sources of information predominating among the early categories of adopters and customer requirements predominating among the later ones, all with respect to the adoption of CPM.

Cosmopolite information sources are most important at the awareness stage and localite information sources are more important at the evaluation stage.

The evidence of this study did not support this contention. The balance between cosmopolite and localite sources appeared to be essentially the same for both cases.

Earlier adopters utilize information sources that are in closer contact with the origin of new ideas than late adopters.

There is evidence to support this view from this study. Four of the first five firms to adopt CPM learned of the technique from sources outside the industry. Two of these apparently had sources very near the development source, as they reported knowledge of CPM at dates prior to its general publication. All firms in the later half of the adopters learned of CPM from sources within the construction industry.

Impersonal sources of information are more important than personal sources for relatively early adopters of innovations than for later adopters.

Personal influence from peers is more important for relatively late adopters than for early adopters.

These two generalizations did not appear to be supported by the questionnaire data, primarily because personal or peer group sources played such a small part, as reported by the respondents, in their adoption of CPM.

Early adopters are younger in age than later adopters.

Just the opposite proved the case among the respondents to this study. The mean age of the "early" groups was 51.1 years as opposed to a mean age of 48.9 years for the "late/laggard" group.

Early adopters have more specialized operations than late adopters.

The evidence of this study tended to support this contention. Of the first fifty percent of the adopters, only two of twelve did not have specialized operations. Of the seven firms reporting mixed operations, five fell in the "late/laggard" categories.

The primary research question is now addressed.

Is significant use being made of modern project management techniques by National Capital Area construction contractors?

As far as the use of CPM is concerned, the evidence from this study indicates a definite "yes" answer to the question. As far as the other modern techniques examined, the evidence

indicates a "no" response. Construction contractors, like other businessmen, will adopt different management techniques only if convinced that this will improve their profits. The paucity of information concerning LOB and Linear Programming techniques in American construction management would indicate that no one has as yet mounted an effort to convince the construction industry of their profitability.

APPENDIX A

SAMPLE CONSTRUCTION MANAGEMENT TECHNIQUE QUESTIONNAIRE

Section A: General Characteristics of the Firm

1. What is your firm's approximate annual dollar volume of construction? $____________________.

2. What types of construction do you perform?

   ______a. Building
   ______b. Highway
   ______c. Heavy
   ______d. Utilities
   ______e. Railroad

3. For whom do you do the majority of your construction?

   ______a. Federal Government
   ______b. State or Local Government
   ______c. Private Sources

4. What is the approximate age of the principal officer(s) of your firm?

   ______a. 21-30 years old
   ______b. 31-40 years old
   ______c. 41-50 years old
   ______d. 51-60 years old
   ______e. 61-70 years old

5. What is the educational background of the principal officer(s) of your firm?

   ______a. No college degree
   ______b. College bachelors degree
   ______c. College advanced degree

6. What is your principal criteria for selecting a project management technique for a specific job?

   ______a. Job size
   ______b. Job complexity
   ______c. Combination of job size and job complexity
   ______d. Use the same technique for all jobs
   ______e. Techniques specified by contracting agency (owners)

Section 3: Technique: Bar (Gantt) Charts

Please give only one answer to each question unless otherwise requested.

1. Have you ever employed this technique?

_____a. Yes, utilizing electronic computers
_____b. Yes, but not utilizing electronic computers
_____c. No

2. If your answer to question 1 is "No," what is the primary reason you have not used it?

_____a. Was not aware of this technique or unfamiliar with its use.
_____b. Consider it too complex for my operations
_____c. Consider it too costly for projected benefits
_____d. Both too complex and too costly.

If your answer to question 2 was "not aware of this technique," skip to question 1, in Section C.

3. When did you first become aware of this technique? 19____.

4. When did you first adopt this technique? 19____.

5. How did you first become aware of this technique?

_____a. Printed literature
_____b. Fellow contractors
_____c. Industry presentations (AGC meetings, etc.)
_____d. Non-industry formal presentations (College courses,etc)
_____e. Owner (Contracting agency) requirements.
_____f. Other non-Construction Industry sources.

6. What primarily led you to first adopt this technique?

_____a. Printed literature
_____b. Recommendation of fellow contractors
_____c. Industry Presentations (AGC meetings, etc.)
_____d. Non-industry formal presentations (College courses,etc)
_____e. Owner (Contracting agency) requirements
_____f. Other Non-Construction Industry sources

7. How long have (did) you use this technique? ________years

8. If you have discontinued its use, what was the principal reason?

_____a. Too complex for my firm
_____b. Too costly for benefits derived
_____c. Both too costly and too complex
_____d. Replaced with a better, but more complex method.

If you have discontinued the use of the technique, skip to question 1 of Section C.

9. What is your primary reason for continuing the use of this technique?

_____a. Believe it increases profit over other techniques
_____b. Believe it allows better control of the job
_____c. Believe its use allows more accurate bids
_____d. Both increased profit and better job control
_____e. Increased profit, better job control and better bids.
_____f. Required by owners (Contracting agencies)

10. On approximately what percentage of your jobs do you use this technique?

_____a. 1-20%　　_____c. 41-60%　　_____e. 81-99%
_____b. 21-40%　　_____d. 61-80%　　_____f. All

11. Who contributes inputs to the use of this technique in your firm? (more than one answer appropriate)

_____a. Job-site Supervisors　　_____e. Purchasing Dept.
_____b. Project Manager　　_____f. Subcontractors
_____c. Outside Consultants　　_____g. Top Management
_____d. Estimators

12. In what phases of construction management do you utilize this technique? (more than one answer appropriate)

_____a. Planning　　_____d. Cost Collection
_____b. Scheduling　　_____e. Resource Allocation
_____c. Monitoring Progress　　_____f. Payment Requests

(Identical Sections to that for Gantt Chart provided for CPM, Line of Balance and Linear Programming)

APPENDIX B

FIRMS TO WHICH QUESTIONNAIRE WAS SENT

American Construction Company, Inc.

Associated Builders, Inc.

Ball, Gordon H., Inc.

Bays, Jack, Inc.

Bateson, J. W., Co., Inc.

Briscoe, Frank, Co., Inc.

Cannon Construction Corporation

Cladny, M., Construction Co., Inc.

Coe Construction, Inc.

Consolidated Engr. Co., Inc.

Corning Construction Corp.

Crough, Edw. M., Inc.

Davis, Edwin, Builder, Inc.

DeLuca Construction Corp.

Equitable Construction Co., Inc.

Friel, Edw B., Inc.

Fuller, George A., Company, Inc.

Gilbane Building Co.

Gilles & Cotting, Inc.

Glen Construction Company

Grimberg, John C., Co., Inc.

Grunley-Walsh Construction Co., Inc.

Head Construction Co.

Hyman, George, Construction Co.

Intercounty Construction Corp.

Kiewit, Peter, Sons' Co.

Klingensmith, William F., Inc.

Lawrence, J. R., Co., Inc.

Lipscomb, Wm. P., Co., Inc.

Martin, George C., Inc.

Massman-Kiewit-Early

McDermott Associates, Inc.

McShain, John, Inc.

Miller Bros. of Arlington, Inc.

Morrison-Knudsen Co., Inc.

Noonan, R. S., Inc.

Norair Engr. Corp.

P & Z -Mergentime

Riddle, Charles H., Co.

Shea, J. F.,Co, Inc.

Simpson, Eugene & Brother, Inc.

Skinker & Garrett, Inc.

Thomas, Eugene, Construction Co., Inc.

Tompkins, Charles H., Co.

Tuckman-Barbee Construction Co., Inc.

Turner Construction Company

Underground Construction Co., Inc.

Utley-James, Inc.

Volpe Construction Co., Inc.

Whitlow, M. L., Inc.

Whitty Construction Co.

Yoder, Thomas W., Co., Inc.

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